MULTIPLE CHANNEL JOINT DECODING AT MOBILE HANDSET

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to the field of communications, and in particular to CDMA decoding techniques in a multi-channel handset in IS2000.

2. Description of Related Art

Code Division Multiple Access (CDMA) is a commonly used spread-spectrum communications technique wherein an information signal is encoded by one of many code sequences before it is transmitted. The received signal is decoded by the same code sequence to reproduce the original information signal. Transmissions from multiple transmitters can be simultaneously communicated via a common channel by employing different code sequences for each transmitter, provided that the code sequences have particular uniqueness characteristics. The uniqueness characteristics of acceptable codes substantially provide that a coherent output will only be produced when the received signal corresponds to a signal that is encoded using the same code sequence. Each code is orthogonal, or non-correlated, to each other, so that signals that are not encoded using the same code sequence as the decoding code sequence are decoded as noise signals. In a conventional CDMA system, such as a cellular telephone network, the network controller, or base station, allocates and deallocates code sequences on demand, so that each of the transmitters can transmit over the same network without interference from other transmitters.

Conventional CDMA receivers include multiple correlators, each using the same code sequence but at different phase delays. Ideally, only the correlator that is synchronous with the transmitted code would produce a coherent output, and each of the out of phase correlators would decode the received signals as noise. Typically, however, the receiver receives multiple copies of the transmitted signal, at different phases, caused by reflections of the transmitted signal off building and such. The phase differences are caused by the different paths that the reflected signals take from the transmitter to the receiver. This multipath effect is used advantageously by conventional CDMA receivers by combining the outputs of the multiple correlators that receive a reflection of the same transmission, at a different phase.

The use of cellular communications has increased dramatically, and is expected to continue to increase. This increase is associated with an increase in the number of users of cellular communications, as well as an increase in the amount of communications required per user.

With this increased use of cellular communications, the requirement for different codes has increased. The commonly used IS-95 standard, circa 1995, requires the use of 64 bit orthogonal Walsh codes, whereas the newer IS2000 standard, circa 2000, allows the use of both Walsh codes and Quasi-Orthogonal Function (QOF) codes of different lengths. The use of codes of different lengths, and codes that are not necessarily completely orthogonal with every other code has led to an increase in cross-channel interference. In addition to the interference caused by the use of non-orthogonal codes, interference may also occur between codes of different length, because a short code may, for example, be non-orthogonal to particular segments of a longer code.

The increased requirement for communications per user includes the requirement for multiple channels per user handset. For example, handsets are available that provide for the simultaneous communications over a voice channel and a data channel. A conventional multi-channel handset includes multiple correlators, each correlator being operated with a code associated with one of the channels. For example, an example two-channel receiver may contain six correlators, three operating with one code, at different phases from each other (for multipath reception) and three operating with the other code, also at different phases from each other.

The use of non-orthogonal codes also has an adverse effect on receivers that use multiple correlators to overcome, or take advantage of, multipath effects. If a correlator detects a slight correlation, this correlation may be the result of a reflection of the desired signal, and therefore combining its result with the results from other correlators will be beneficial. If, however, the correlation is the result of an other, non-orthogonal, channel's transmission, combining its result with the results from other correlators will be detrimental.

A variety of techniques for overcoming the interference caused by the increased use of non-orthogonal codes are available for use at a base station. US patent 5,506,861 "SYSTEM AND METHOD FOR JOINT DEMODULATION OF CDMA SIGNALS", issued 9 April 1996 to Bottomley et al, and incorporated by reference herein, presents a scheme for demodulating single and multiple signals in a multipath, time-dispersion environment, with or without taking

intersymbol interference into account. This scheme determines each bit, or symbol, value on each of a plurality of channels by minimizing an error function that is based on the totality of channels. The minimization process also includes a dynamic adjustment of filter coefficients within each channel. The complexity of this scheme, however, renders it infeasible for embodiment in a handset, and this scheme does not directly address codes of varying sizes.

BRIEF SUMMARY OF THE INVENTION

It is an object of this invention to provide a receiving system and method for use in a multi-channel handset that reduces the effects of non-orthogonal channel interference. It is a further object of this invention to provide a receiving system and method to facilitate the processing of CDMA codes of different sizes in a multi-channel environment.

These objects, and others, are achieved by providing a system and method that suppresses the interference caused by non-orthogonal signals on multiple channels of the same receiver. Generally, a particular handset is unaware of transmissions to other handsets, and thus cannot efficiently suppress the adverse effects of these transmissions. In a multi-channel receiver, however, the receiver is aware of the codes that are allocated to each of the channels, and thus, can be configured to suppress the effects of the interferences caused by non-orthogonal transmissions of these multiple-channels. The correlation among the multiple codes that are allocated to a receiver is computed, and the inverse of this correlation is applied to the output of the correlators assigned to each code, thereby suppressing the effects of using non-orthogonal codes for transmissions to the same receiver. If different sized codes are allocated to the same receiver, the correlation of the shorter code and a corresponding segment of the longer code is computed. The inverse of the correlation for this segment is applied to the output of the correlators, corresponding in time to the processing of the shorter code and this segment of the longer code. The correlation of the shorter code and each shorter-code-length segment of the longer code is similarly determined and its inverse applied to the outputs of the correlators. An output corresponding to the entire longer-length code is determined by combining the intermediate outputs corresponding to each shorter-code-length segment.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is explained in further detail, and by way of example, with reference to the accompanying drawings wherein:

FIG. 1 illustrates an example block diagram of a multi-channel CDMA handset in accordance with this invention.

FIG. 2 illustrates a timing diagram corresponding to the processing of codes of different length in accordance with this invention.

Throughout the drawings, the same reference numerals and characters indicate similar or corresponding features or functions.

DETAILED DESCRIPTION OF THE INVENTION

For ease of reference and understanding, this invention is presented using the paradigm of a two-channel CDMA handset, although the principles of this invention are equally applicable to more than two channels, or CDMA systems other than handsets, as will be evident to one of ordinary skill in the art in view of this disclosure.

FIG. 1 illustrates an example block diagram of an example multi-channel (two-channel) CDMA handset 100. At the output of the receiver 110, the received signal can be represented as:

$$\underline{s} = X_1 w_1 \underline{C}_1 + X_2 w_1 \underline{C}_2 \qquad \text{(transmitted signals on each channel)}$$

$$+\sum_i \left(X_1 w_i \underline{C}_1(t-\tau_i) + X_2 w_i \underline{C}_2(t-\tau_i) \right) \qquad \text{(multipath of transmitted signals)}$$

$$+\sum_k \sum_i \left(X_k w_k \underline{C}_k(t-\tau_i) \right) \qquad \text{(all paths of all other signals)}$$

$$+\underline{n_o} \qquad \text{(all other noise)}$$

where X_c is the transmitted information symbol on code-channel c, w_i is the weight, or attenuation, associated with the communications path i, and $\underline{C}_c$ is the channel code c. Depending upon the particular encoding scheme used, the symbol X may be a binary, one-bit, value, or an M-ary, multi-bit value, and is termed a symbol. Because the code is applied to the entire transmitted symbol, the code is represented as a vector $\underline{C}$, as indicated by the underscore. For ease of understanding, equal length codes will be assumed. A technique for processing different length codes is also presented hereinafter.

The received signal is fed to a plurality of decoder paths, or "fingers", each having a different phase delay 120. Within each path i, a filter 130 compensates for the effects of channel weight and other factors, and this filtered signal is applied to correlators 140a, 140b to decode the signals $y_{i,1}$ and $y_{i,2}$ corresponding to the transmitted symbol X_1 and X_2. Note that, as contrast to a conventional base station that receives multiple transmissions from a variety of asynchronous handsets, the multiple-channel signals X_1 and X_2 of the same user are synchronous with each other. Thus, the finger that is in sync with one of the channel codes of the transmitted signal, or in sync with one of codes of the multipath reflections of the transmitted signal, will also be in sync with each of the other channel codes. This synchronization is represented by the correspondence of each of the terms $\underline{C}_1$ and $\underline{C}_2$ in the above, and subsequent, equations.

Without loss of generality, the filtered receive signal at the output of a filter 130, after compensation for the channel weight, can be represented as:

$$\underline{r}_i = X_1\underline{C}_1(t-\tau_i) + X_2\underline{C}_2(t-\tau_i) + \underline{n}$$ (transmitted signals plus noise)

where the effects of multipath and all other signals and noise factors are included in the noise figure $\underline{n}$, because these are all noise elements to a particular finger.

The output y from a correlator 140 at phase i can be represented as:

$$y_{i,1} = \left(X_1\underline{C}_1(t-\tau_i) + X_2\underline{C}_2(t-\tau_i) + \underline{n}\right)\bullet\underline{C}_1$$

$$y_{i,2} = \left(X_1\underline{C}_1(t-\tau_i) + X_2\underline{C}_2(t-\tau_i) + \underline{n}\right)\bullet\underline{C}_2,$$

where $\bullet$ is the inner product. In a multipath decoding system, the outputs y from each finger are combined via a multipath processor 160, and the determination of the symbol value S_1 and S_2 corresponding to the transmitted symbols X_1 and X_2 is based on the composite of the outputs $y_{i,1}$ and $y_{i,2}$, using averaging and other techniques, common in the art. If a single finger is used, or if no multipath signals are detected, the output symbols S_1 and S_2 are based on the single finger outputs y.

If a correlator 140 is in phase with the reference phase, either directly or via a multipath, the output of the correlator can be represented as:

$$y_1 = X_1 + X_2\left(\underline{C}_2\bullet\underline{C}_1\right) + \underline{n}\bullet\underline{C}_1$$

$$y_2 = X_1\left(\underline{C}_1\bullet\underline{C}_2\right) + X_2 + \underline{n}\bullet\underline{C}_2.$$

Note that, if the two codes C_1 and C_2 are orthogonal, the inner product of the two codes will be zero. Thus, in the absence of noise that is correlated to the CDMA code, and if the two codes are orthogonal, the output y will correspond to the transmitted symbol X.

In a conventional CDMA receiver, the symbol value corresponding to the signal y is determined by comparing the value y to a range of values corresponding to the different symbol values. In the case of a binary signal, the encoding is typically +/- 1, corresponding to a logic-high and logic-low value. Thus, in a conventional system, if the output y of the correlator 140 is positive, a logic-high is reported as the determined binary value corresponding to the transmitted signal X; if the output y is negative, a logic-low is reported.

If non-orthogonal codes are used, the inner product of the codes C_1 and C_2 will not be 0, and each output y_1 and y_2 will be adversely affected by the signal that is received on the alternate channel, X_2 and X_1, respectively. If additional channels are provided, and non-orthogonal codes are used, the adverse effects caused by the interference among these channels will increase, due to the non-zero correlation among the codes.

In accordance with this invention, a decorrelator 150 is provided that suppresses the adverse effects caused by the use of non-orthogonal codes. The correlation between the two codes can be represented as:

$$R = \begin{bmatrix} \underline{C}_1\underline{C}_1 & \underline{C}_1\underline{C}_2 \\ \underline{C}_2\underline{C}_1 & \underline{C}_2\underline{C}_2 \end{bmatrix}.$$

Note that, because the codes C_1 and C_2 are known to the multi-channel receiver, this correlation, and its inverse, can be determined at the multi-channel receiver. Note also, that, because the codes are synchronous with each other, the correlation term is independent of phase. The inverse of this determinable correlation is used at the decorrelator 150 to suppress the effects of non-orthogonal codes, to produce a decorrelated set of signals z, as follows:

$$\begin{bmatrix} z_1 \\ z_2 \end{bmatrix} = R^{-1}\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = R^{-1}\begin{bmatrix} \underline{r}\bullet\underline{C}_1 \\ \underline{r}\bullet\underline{C}_2 \end{bmatrix}.$$

Each of the signals z_1 and z_2 is used in accordance to this invention to determine the symbol value corresponding to the transmitted symbol X_1 and X_2, respectively. That is, for example, if the transmitted signal is a binary +/- 1 value, the logic value corresponding to the transmitted symbol X is determined by the sign of the signal z. In a multipath decoding system, the outputs z

from each finger are combined, and the determination of the symbol value is based on the composite of these outputs, using conventional multipath decoding techniques.

As illustrated by the equations above, by applying the inverse of the correlation between the codes C_1 and C_2, the effects caused by the use of non-orthogonal codes C_1 and C_2 are suppressed. If the codes are, in fact, orthogonal, the correlation between the codes is zero, and its inverse is unity, and the decorrelation operation will have no effect. As also illustrated by the equations above, the correlation matrix and its inverse are not dependent upon phase, nor upon the value of the received symbols, and thus may be computed when the codes are initially allocated, and used thereafter for the duration of the received communications on the multiple channels. Note that, because the application of this decorrelation process is an enhancement to the conventionally determined signals y, a unity value for the inverse of R may be applied at the decorrelator 150, while the inverse is being calculated, thereby avoiding any delays in communication if the processor that is used for determining this inverse is relatively slow.

FIG. 2 illustrates a timing diagram corresponding to the processing of codes of different length in accordance with this invention. In this example, a first code $\underline{C}_1$ is four times as long as second code $\underline{C}_2$. The input symbols X_1 that are encoded via the first code $\underline{C}_1$ are correspondingly four times as long as input symbols X_2 that are encoded via the second code $\underline{C}_2$. That is, four symbols X_2 are communicated for each symbol X_1. In FIG. 2, each sequential symbol X is identified, as X(1), X(2), X(3), and so on. In the span of symbol $X(1)_1$, four shorter symbols, $X(1)_2$, $X(2)_2$, $X(3)_2$, and $X(4)_2$, occur. When the next symbol on the first channel, $X(2)_1$, commences, the fifth shorter symbol, $X(5)_2$, commences. The longer code $\underline{C}_1$ is illustrated as four segments $\underline{C}_1[1]$ $\underline{C}_1[2]$ $\underline{C}_1[3]$ and $\underline{C}_1[4]$, each segment being the same length as the shorter code $\underline{C}_2$.

In accordance with this invention, signal values y are produced at each interval j, j=1,4, corresponding to the shorter code $\underline{C}_2$, as follows:

$$\begin{bmatrix} y_1[j] \\ y_2[j] \end{bmatrix} = \begin{bmatrix} \underline{r}[j] \bullet \underline{C}_1[j] \\ \underline{r}[j] \bullet \underline{C}_2 \end{bmatrix}.$$

A correlation between the codes can be represented as:

$$R[j] = \begin{bmatrix} \underline{C}_1[j]\underline{C}_1[j] & \underline{C}_1[j]\underline{C}_2 \\ \underline{C}_2\underline{C}_1[j] & \underline{C}_2\underline{C}_2 \end{bmatrix};$$

that is, the correlation at each segment is defined as the correlation between the shorter code and each corresponding segment of the longer code. This segment-specific correlation is used to suppress the effects of the non-orthogonality of the shorter code and the segments of the longer code at the decorrelator 150 as follows:

$$\begin{bmatrix} z_1[j] \\ z_2[j] \end{bmatrix} = R[j]^{-1} \begin{bmatrix} y_1[j] \\ y_2[j] \end{bmatrix} = R[j]^{-1} \begin{bmatrix} \underline{r}[j] \bullet \underline{C}_1[j] \\ \underline{r}[j] \bullet \underline{C}_2 \end{bmatrix}.$$

The output value z_2 at each interval ($z(1)_2$, $z(2)_2$, $z(3)_2$, $z(4)_2$, $z(5)_2$, etc.) corresponds to a different input signal X_2 ($X(1)_2$, $X(2)_2$, $X(3)_2$, $X(4)_2$, $X(5)_2$, etc.). Because the code $\underline{C}_1$ extends across four time intervals j, each of the four output values $z_1[j]$ form a segment of the output value z_1 corresponding to the four-segment wide input signal X_1. That is, $z(1)_1[j, j=1,4]$ corresponds to $X(1)_1$, $z(2)_1[j, j=1,4]$ corresponds to $X(2)_1$, and so on. Note that, because each of the four segments of the output z_1 corresponds to the same input value X_1, any of the output values $z_1[j]$ can be used to determine the corresponding input signal X_1. In accordance with this invention, the determination of the input signal X_1 is based on a composite of the individual output values $z_1[j]$ corresponding to each segment of the code $\underline{C}_1$. In the binary case, for example, the sign of the sum of the values $z_1[j]$ may be used to determine the output symbol. In an M-ary encoding, the average of the values $z_1[j]$ may also be used. Alternatively, each output segment $z_1[j]$ may be used to provide a symbol, and a voting scheme may be used to select the composite of the segments corresponding to the input symbol X_1. In a multipath decoding system, the composite outputs z from each finger are combined via the multipath processor 160, and the determination of the symbol value is based on the composite of these outputs, using conventional multipath decoding techniques, such as a weighted average.

Note that, although the use of segments of a longer code to decode corresponding segments of an information signal is presented in the context of the use of a decorrelator 140 to suppress the effects of a correlation between a shorter code and each segment, this technique may also be applied independent of the decorrelator 140. That is, for example, to reduce memory requirements, or to reuse designs that are configured for a shorter code, longer codes can be processed via the segmented decoding technique detailed above. Similarly, the size of the segments need not be constrained to a length of a code. Preferably, a segment should not extend across a boundary between two information symbols, and this can be achieved by selecting a segment length that is a common multiple of each of the code lengths.

The foregoing merely illustrates the principles of the invention. It will thus be appreciated that those skilled in the art will be able to devise various arrangements which, although not explicitly described or shown herein, embody the principles of the invention and are thus within its spirit and scope. For example, although specific delay blocks 120 are illustrated, the input stream of bits may be contained in a continuous shift register, and the different fingers are configured to merely extract the bits from different segments of the shift register. In like manner, although a multi-fingered embodiment is illustrated for processing multipath signals, a single-fingered embodiment may also be used. These and other system configuration and optimization features will be evident to one of ordinary skill in the art in view of this disclosure, and are included within the scope of the following claims.